Effect of acute resistance exercise on postexercise energy expenditure and resting metabolic rate

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MELBY, CHRISTOPHER, CYNTHIA SCHOLL, GLENDA EDWARDS, AND RICHARD BULLOUGH. Effect of acute resistance exercise on postexercise energy expenditure and resting metabolic rate. J. Appl. Physiol. 75(4): 1847-1853, 1993.—Two separate experiments were performed to determine the effect of acute resistive exercise on postexercise energy expenditure in male subjects previously trained in resistive exercise. In experiment 1, after measurement of their resting metabolic rate (RMR) at 0700 h and their ingestion of a standardized meal at 0800 h, seven subjects (age range 22-40 yr) beginning at 1400 h completed a 90-min weight-lifting protocol. Postexercise metabolic rate (PEMR) was measured continuously for 2 h after exercise and compared with a preexercise baseline. RMR was measured the following morning 15 h after completion of the workout. In experiment 2, six different men (age range 20-35 yr) completed a similar experimental protocol as well as a control condition on a separate day in which metabolic rate was measured for 2 h after a period of quiet sitting. For both experiments, PEMR remained elevated for the entire 2-h measured recovery period, with the average oxygen consumption for the last 6 min elevated by 11-12%. RMR measured the morning after exercise was 9.4% higher in experiment 1 and 4.7% higher in experiment 2 than on the previous day. In experiment 2, the postabsorptive respiratory exchange ratio was significantly lower the morning after the exercise bout. Strenuous resistive exercise may elevate PEMR for a prolonged period and may enhance postexercise lipid oxidation.

weight lifting; postexercise oxygen consumption

NUMEROUS STUDIES HAVE EXAMINED the impact of steady-state aerobic exercise on the magnitude and duration of excess postexercise oxygen consumption (EPOC) (2-5, 26). Although the data are not entirely consistent, they suggest that exercise intensity has a greater impact on the magnitude of EPOC than does exercise duration (3, 11, 26). From a practical standpoint, most authors agree that for individuals who routinely perform three to five sessions per week of 30-40 min of low- to moderate-intensity exercise, the magnitude of excess energy expenditure after acute exercise is of little short-term consequence to weight control (24). However, it appears that higher-intensity exercise of longer duration may result in a prolonged recovery period, contributing to significant postexercise caloric expenditure. Such exercise may even have a residual effect on resting metabolic rate (RMR) when measured the day after exercise. Although some authors suggest that chronic exercise produces training adaptations that lead to higher RMR values (22-24, 30), there exists the possibility that RMR measurements are higher because of residual metabolic perturbations from the previous exercise bout(s).

To date, few studies have addressed the impact of non-steady-state resistance exercise on the postexercise metabolic rate. Wilmore et al. (34), Stone et al. (28), and Triplett et al. (31) examined EPOC after bouts of circuit training, Olympic-type weight lifting, and multiple sets of back parallel squats, respectively, but none of the calorimetry measurements extended beyond 20 min postexercise. Burleson et al. (7) reported a significantly higher EPOC in young men at 30 min, but not at 60 or 90 min, after completion of a circuit of resistance exercises compared with EPOC after steady-state aerobic exercise. In a previous study (20) we found that, after a 45-min bout of resistance exercise, metabolic rate remained elevated for >1 h and possibly longer compared with that measured for 1 h after a control condition of quiet sitting on a separate day. None of these studies examined the possibility of a prolonged effect of such exercise on metabolic rate. We previously reported that college wrestlers exhibited higher RMR values than nonwrestling control subjects (19, 25), suggesting the possibility that participation in vigorous non-steady-state exercise (2.5 h of wrestling practice) could have a residual effect on RMR when measured 12-15 h later.

In the present paper we report the results of two separate experiments designed to determine the effects of acute strenuous resistance exercise on metabolic rate during the 2 h immediately after exercise and on RMR the following day, measured ~15 h after cessation of exercise.

METHODS

Subjects

A total of seven male subjects participated in the first experiment, and six different males were subjects in the second experiment. All were between the ages of 20 and 40, were free of any known illness or injury that could influence metabolic rate, were weight stable (defined as no more than a 2-kg weight fluctuation within the previous 6 mo), and were regular participants in weight-lifting exercise (3-4 times/wk for ≥1 h/session). None of the subjects was a competitive body builder, and all denied use of anabolic steroids or other growth-enhancing aids. All subjects were informed both orally and in writing of the general purpose of the investigation. Each subject

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TABLE 1. Experimental protocol for expt 1

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Time</th>
<th>Activity</th>
</tr>
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<tbody>
<tr>
<td>0700-0800</td>
<td>RMR 1</td>
<td>Breakfast</td>
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<tr>
<td>0830-0900</td>
<td></td>
<td>Preexercise baseline metabolic rate</td>
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<tr>
<td>1330-1400</td>
<td>Exercise</td>
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<tr>
<td>1400-1530</td>
<td></td>
<td>EPOC</td>
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<tr>
<td>1530-1730</td>
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<td>Dinner</td>
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<tr>
<td>1730-1830</td>
<td></td>
<td>RMR 2</td>
</tr>
<tr>
<td>0700-0800</td>
<td>RMR 1</td>
<td>Breakfast</td>
</tr>
</tbody>
</table>

RMR, resting metabolic rate; EPOC, excess postexercise oxygen consumption.

Experiment 1

Table 1 displays the scheduled protocol completed by each of the seven subjects. At 0700 h on day 1, RMR was measured for 1 h by indirect calorimetry with each subject in a 12-h-fasted state. After measurement of RMR, subjects were fed a standardized breakfast (meal size and composition are described later in “Hemtary intake”), which was consumed by 0830 h. Subjects were then allowed to leave the laboratory but were told to remain sedentary and to abstain from ingesting any food or beverage except water. Subjects returned to the laboratory at 1330 h, at which time the preexercise resting energy expenditure was measured for 30 min; this served as the baseline oxygen consumption (VO,) for determining EPOC. Beginning at 1400 h, each subject then performed a 90-min bout of weight-lifting exercise. Calorimetry was begun ~5 min after the last set of lifts and continued for 2 h. At 1730 h subjects were fed a standardized dinner and were told to return home, to remain sedentary, and to refrain from consumption of any food or beverage except water. They returned the following morning at 0700 h for their second 1-h RMR measurement, ~15.5 h after cessation of exercise and 12 h after consumption of their previous (evening) meal.

Indirect calorimetry. Measures of VO, CO, production (VCO,), and respiratory exchange ratio (RER) were made by indirect calorimetry by use of a ventilated hood attached to an automated metabolic cart (Sensormedics, Yorba Linda, CA). The O, and CO, analyzers were calibrated before and after each test with known gas concentrations (zero gas-100% N,, precision calibration gas-20% O,1% CO,). The volume transducer was also calibrated using a pump to deliver fixed volumes at three different flow rates, and temperature was calibrated using a thermometer adjacent to the temperature transducer. All values obtained from indirect calorimetry were standardized STPD. The reliability of repeated RMR and postabsorptive RER measurements in our laboratory has been previously reported with an average coefficient of variation of 3.1 ± 1.3% for RMR and 5.3 ± 2.4% for RER (6).

RMR measurement. On reporting to the laboratory for RMR measurement, subjects were initially weighed on a balance beam scale, and height was recorded using an attached stadiometer. Subjects were then placed in a supine position on a comfortable bed, with the head enclosed in a clear Plexiglas canopy. The bed was located in a well-ventilated private semidarkened room with the temperature maintained between 22 and 24°C. The canopy was connected to the gas analyzers by a hose that passed through the wall between the room and the laboratory. After a 30-min habituation period, the VO, and VCO, data were collected for the final 30 min and averaged to determine RMR with the Weir equation (33). Twenty-five minutes into the 30-min habituation period, each subject was inspected to ensure he was comfortable and awake. All values during the final 30 min were included in calculation of the subject’s RMR value.

EPOC measurement. The preexercise resting VO, and VCO, were measured for 30 min before the exercise bout in a manner similar to RMR measurement. This VO, served as the resting baseline VO, which was subtracted from the postexercise period to determine the EPOC. Within 3 min of completing the 90-min exercise bout, subjects were returned to the respiratory canopy for continuous measurement of VO, VCO, and RER over a 2-h period. With a 2-min instrument wash-in period, accuracy rate measures were obtained ~5 min after cessation of exercise. Six-minute averages were obtained during the 2-h period for each subject, and from these values the average resting preexercise VO, was subtracted.

Weight-lifting protocol. The exercise treatment was a single session of resistance exercise similar to that described by Wallace et al. (32). Subjects performed six sets of 10 different weight-lifting exercises for a total of 60 sets. The weight for each lift was initially set at 70% of the subject’s preestablished one repetition maximum. Subjects performed as many repetitions as possible for each set; usually 8–12 repetitions per set were performed before failure. For several subjects, the weight was lowered for a few lifts in one or more of the last three sets to ensure a minimum of 8 repetitions performed. The 10 different lifts were divided into five groups of two different lifts emphasizing different muscle groups, and the lifts were executed in pairs. There was a 3-min interval between the start of one set and the start of another set of the same exercise. Within the 3-min interval, subjects performed a set of the other paired lift. Six sets of each of the paired lifts were performed in an 18-min period, with all 10 lifts (5 pairs) performed in 90 min. The protocol included both upper and lower body exercises with the following order of paired lifts: bench press and bent-over row; leg extension and leg curl; military press and sit-ups; biceps curls and triceps extensions; and, finally, half-squats and lateral raises (arm abductions for deltoids). Subjects were closely supervised and were required to use
TABLE 2. Experimental protocol for expt 2

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<tbody>
<tr>
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<td>Supper</td>
<td>1730</td>
<td>Supper</td>
<td>1400–1540</td>
<td>Exercise</td>
<td>1400–1540</td>
<td>Rest</td>
<td>1545–1745</td>
<td>EPOC</td>
<td>1545–1745</td>
<td>EPOC</td>
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</table>

In addition to use of a control condition, the exercise protocol for experiment 2 was shortened to five sets of each respective lift, with a 4- rather than 3-min interval between each set of the same exercise. This change was made because of complaints of exertion-induced nausea in two participants in the first study. Before this study was commenced, the energy cost of the exercise protocol was estimated by continuous indirect calorimetry with a face mask (Hans Rudolph, Kansas City, KA) in two volunteers during the entire 96 min of resistance exercise. The gross O₂ cost for the 96 min of exercise was determined by averaging all 30-s values during the entire exercise session. The gross caloric cost was determined by multiplying the total exercise VO₂ by 5 kcal/l O₂. We used this value of 5 kcal rather than relying on the caloric equivalent based on the RER, because the latter does not provide an accurate reflection of substrate utilization when it is influenced by pH-induced respiratory changes that occur with strenuous exercise. It was assumed that carbohydrate was the primary macronutrient substrate for the resistive exercise. Subject 1 (body wt 70 kg, exercise volume 24,160 kcal) had a gross caloric cost of 661 kcal and a net cost (gross caloric cost - RMR) of 534 kcal for the 96-min weight-lifting session. Subject 2 (body wt 90.4 kg, exercise volume 29,383 kcal) had a gross caloric cost of 864 kcal and a net cost of 695 kcal. These values correspond to ~7-9 kcal expended per minute of resistance exercise, including the resting periods between sets.

For both conditions, the caloric intake and dietary macronutrient composition of the subjects were controlled by having subjects consume meals prepared by a research dietitian. Subjects were provided with evening meals before the day of each condition based on 42 kcal/kg body wt ÷ 3. On the days of exercise and quiet sitting they were given breakfast (1,000–1,200 kcal) at 0700 and lunch (700–1,000 kcal) at 1145 h. They were also provided an evening meal (1,200–1,400 kcal) at 1830 h, which was consumed by 1900 h, after measurement of EPOC for the exercise treatment. The evening meals before and after the resistance exercise were identical within each subject. The composition of the meals was similar to that of the first experiment.

Data Analysis

For experiment 1, EPOC was determined by subtracting the average preexercise baseline obtained for 30 min from the postexercise VO₂ data for each subject (averaged for each 6-min interval). Because this experiment did not include parallel measures of VO₂ on a control day, the postexercise data from experiment 1 are presented without statistical tests when the 2-h recovery period is compared with the preexercise baseline values. The RMR data were analyzed using a paired t test, which compared values the morning of and the morning after the exercise treatment. For experiment 2, the RMR data were analyzed in a similar fashion. However, the 2-h EPOC data were analyzed using a within-subjects repeated-measures analysis of variance (ANOVA), comparing each 6 min postexercise VO₂ with each of the VO₂ values at the same time period during the 2 h after the control period of quiet sitting. Post hoc comparisons were made between conditions at each 6-min time point during the 2-h recovery period by use of the least significant difference (LSD) test. The statistical tests were performed using the Statistical Analysis System (SAS,
TABLE 3. Physical characteristics of subjs for expts 1 and 2

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>Weight Lifted,* kg</th>
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</thead>
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<td>Means ± SE</td>
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<td>180</td>
<td>82.0</td>
<td>26,849</td>
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</table>

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>Weight Lifted,* kg</th>
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</thead>
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<tr>
<td>5</td>
<td>27</td>
<td>176</td>
<td>74.0</td>
<td>24,108</td>
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<tr>
<td>6</td>
<td>35</td>
<td>173</td>
<td>74.0</td>
<td>27,236</td>
</tr>
<tr>
<td>Means ± SE</td>
<td>27±2.9</td>
<td>179±3.0</td>
<td>82±5.5</td>
<td>26,884±1,033</td>
</tr>
</tbody>
</table>

* Weight lifted (kg) × no. sets × no. repetitions.

Cary, NC). The level of statistical significance was set at \( P < 0.05 \). Values are reported as means ± SE.

RESULTS

Experiment 1

Some physical characteristics of the participants are provided in Table 3. There was considerable variability in the amount of weight lifted during the 90 min exercise session, ranging from 15,000 kg to almost 40,000 kg. As expected, the larger individuals lifted a greater volume of weight.

During the 2-h recovery period after the exercise bout for each subject, postexercise \( \text{VO}_2 \) at every one of the 20 6-min time points remained higher than his preexercise (baseline) \( \text{VO}_2 \). For the last 6 min of the 2-h recovery period, the average \( \text{VO}_2 \) remained 11.4% higher than the preexercise baseline. The average total EPOC (minus the first 5 min of recovery) for the 2 h after exercise was 7.0 ± 1.0 liters \( \text{O}_2 \). For all but one subject, the RER fell below 0.65 during the first 45 min of recovery (presumably due to reduced \( \text{CO}_2 \) expiration to restore the body's bicarbonate pool), which disallowed use of the Weir equation to determine the caloric equivalents per liter of \( \text{O}_2 \) consumed. A value of 4.8 kcal/l \( \text{O}_2 \) was used to estimate the net caloric cost of the recovery period, which accounted for an additional 34 kcal expended above resting values during the 2-h period.

RMR measured the next morning after the afternoon exercise (15 h later) was significantly elevated (\( P < 0.01 \)) compared with that measured under identical conditions the morning before exercise (2,110 ± 80 vs. 1,930 ± 70 kcal). The elevation of RMR occurred in all seven subjects, with the average increase being 9.4% (range 5.4–19.4%) (Fig. 1).

Experiment 2

The physical characteristics of the additional six subjects studied in the second experiment are also presented in Table 3. Despite fewer total sets in this experimental protocol (50 total sets of exercise for expt 2 vs. 60 sets for expt 1), the average volume of weight lifted was slightly higher. The subjects in experiment 2 were younger and weighed more, and several were physically stronger on the basis of their one-repetition maximum values.

The EPOC data are presented in Fig. 2, with \( \text{VO}_2 \) during the 2 h after resistance exercise compared with that performed on a separate day during the 2-h period after the quiet sitting condition. There were significant (\( P < 0.001 \)) main effects of condition and time and a significant (\( P < 0.001 \)) condition × time interaction. Post hoc
contrasts revealed significant differences ($P < 0.01$) at every one of the 20 time points. The average $\text{VO}_2$ during the final 6 min of the 2-h exercise recovery period was 11.7% higher than that during the same time period after quiet sitting. The average EPOC (minus the first 5 min immediately postexercise) was $7.2 \pm 1.2$ liters $\text{O}_2$; the net caloric cost of the recovery period was 34 kcal (range 10–53 kcal).

The morning after exercise, the mean RMR was 4.7% higher ($2,000 \pm 110$ kcal) than that measured the morning before exercise ($1,910 \pm 110$ kcal; $P < 0.05$). Five of six subjects showed an increase in RMR (range 2.0–10.3%), but one subject showed no change (Fig. 1).

For both experiments the RER was slightly lower when measured the morning after the previous day’s resistive exercise than it was the morning before exercise (expt 1: before exercise RER = 0.82, after exercise RER = 0.79, $P = 0.22$; expt 2: before exercise RER = 0.88, after exercise RER – 0.84, $P = 0.03$).

**DISCUSSION**

The results of this two-part investigation indicate that metabolic rate remains elevated above baseline levels during the postexercise period for $\geq 2$ h and probably longer after a bout of resistive exercise of the volume reported here. In all of the 13 subjects studied, metabolic rate as determined by $\text{VO}_2$ was higher at the end of the 2-h postexercise period than the respective resting baseline levels of $\text{VO}_2$. This study also provides evidence for a prolonged elevation of metabolic rate after such exercise, based on the elevation of RMR in 12 of the 13 subjects when measured the following morning 14–15 h after the exercise bout.

**Methodological Issues and Limitations**

Several methodological issues and caveats regarding the two experiments should be addressed. Use of the preexercise baseline to determine EPOC, as occurred in experiment 1, has its limitations because of possible confounding from diurnal variations in metabolic rate. It is also possible that some of the EPOC measured in experiment 1 was the result of greater restlessness (fidgeting) that might occur when subjects are required to lie under the canopy for 2 h compared with the 30-min preexercise baseline measurement. On the other hand, the baseline could be slightly elevated because of some residual postprandial thermogenesis and an anticipatory preexercise arousal. This phenomenon would result in an underestimation of EPOC. We used a control condition in experiment 2 in which the 2-h postexercise $\text{VO}_2$ was compared with a 2-h poststory $\text{VO}_2$, with both measures occurring 4 h after a light meal. In the latter experiment we also measured resting $\text{VO}_2$ for 20 min immediately before the subjects participated in the resistive exercise, and we compared this value with the average $\text{VO}_2$ for the 2 h after quiet sitting. The preexercise values were slightly higher (mean $\text{VO}_2 = 343$ ml) than those for the 2-h control condition (mean $\text{VO}_2 = 326$ ml), suggesting that the use of a preexercise baseline may lead to an underestimation of EPOC. However, even with this caveat, the postexercise $\text{VO}_2$ values in experiment 1 were elevated for every subject at the end of 2 h. It seems reasonable to conclude that exercise of the type studied here does elevate metabolic rate for $\geq 2$ h postexercise, although we believe that, for reasons mentioned above, the EPOC values for experiment 1 should be viewed with caution.

This study was specifically designed not to quantify precisely the caloric cost of the recovery from acute resistive exercise but rather to examine the possibility of a prolonged elevation of postexercise metabolic rate. Five minutes of recovery data were lost from the time each subject completed his last lift to the time when $\text{VO}_2$ and $\text{VCO}_2$ could be determined after he was placed in the respiratory canopy. Because recovery $\text{VO}_2$ would be highest immediately postexercise, the inability to measure $\text{VO}_2$ during this 5-min interval resulted in an underestimation of the 2-h EPOC. Also, indirect calorimetry was discontinued 2 h postexercise when metabolic rates remained elevated.

The lower RER values in the first compared with the second experiment are unexplained inasmuch as the meticulous procedures for calibration of the metabolic cart were identical for both experiments. It has been shown in other studies that there is considerable between-subject variability in fasting RER (26). Because different subjects were used in the two experiments, the RER differences between experiments may reflect normal human variation in postabsorptive fuel utilization.

**Effect of Exercise Mode, Intensity, and Duration on EPOC**

Despite the fact that most of the previous studies that have examined the impact of exercise intensity and duration on EPOC have used endurance rather than resistive exercise as the stimulus, some comparisons of our findings with previous studies are in order. On the basis of studies by Brehm and Gutin (5), Bahr and Sejersted (3), Sedlock et al. (26), and Gore and Withers (11), the EPOC produced by endurance exercise of low to moderate intensity (30–60% of $\text{VO}_{2\text{max}}$) is quite small (typically no more than 3–7 liters of $\text{O}_2$, with recovery to baseline occurring within 15–60 min). The duration of steady-state exercise appears to influence EPOC in a linear fashion (2), whereas increasing exercise intensity beyond 50–60% of $\text{VO}_{2\text{max}}$ may influence EPOC in an exponential manner (3). Bahr et al. (1) recently reported that brief intermittent bouts of exhaustive supramaximal exercise (3 2-min bouts of exercise separated by 3-min rest periods) elevated postexercise metabolic rate for 4 h. Two studies that examined relatively short duration but high-intensity resistive exercise found pronounced elevations of postexercise $\text{VO}_2$ (7, 20). Thus the magnitude and duration of EPOC appear to be influenced more by the intensity than the duration of exercise. Gore and Withers (11) suggested that there is no sustained elevation of metabolic rate after exercise of intensities $< 55\% \text{VO}_{2\text{max}}$ and $< 3$ h duration. Thus the low- to moderate-intensity exercise capable of being performed by the general public produces little excess energy expenditure during recovery and would appear to have little impact on weight control. The benefit of such exercise in terms of caloric expenditure is limited almost entirely to the exercise period itself.
However, several studies found that the combination of high-intensity and long-duration exercise produces prolonged elevations of postexercise metabolic rate. Maehlum et al. (17) exercised eight subjects for 80 min at 70% of VO2 max and found metabolic rates to be elevated for ≥12 h postexercise compared with a control condition in which the subjects did not exercise. Devlin and Horton (8) observed a 3–7% elevation of metabolic rate among individuals subjected to 71 min of intermittent exercise at 85% VO2 max. These findings are similar to those of the present investigation, where postexercise metabolic rates were elevated continuously for ≥2 h in every subject and were also elevated 15 h after exercise when RMR was measured again. Our findings, then, provide further support for the conclusion reached by Gore and Withers (11) that the major determinant of EPOC is exercise intensity.

In the present study, no attempts were made to identify thermogenic factors responsible for the elevation of postexercise metabolic rate, although it has been shown that acute strenuous resistive exercise causes dramatic homeostatic perturbations (12, 15, 29), including elevations of blood lactate (13, 14), catecholamines (15), and anabolic hormones (14). The disruption of resting homeostasis by resistive exercise may be of such magnitude that recovery of various thermogenic factors to true resting levels requires more than a few hours.

It is unknown whether energy expenditure remained elevated during the 13-h period between the end of EPOC measurements and the start of RMR measurements the following morning, although it appears likely that this phenomenon did occur. We have estimated the excess caloric expenditure during this 13-h period on the basis of the assumption that metabolic rate was elevated for each individual during this period by at least as much as his elevation of RMR the following morning. The "extra" calories expended during this 13-h period could be added to the measured 2-h recovery period to estimate the 15-h excess postexercise energy expenditure. This excess caloric expenditure (based on 4.8 kcal/liter O2) averaged 114 kcal for experiment 1 (range, 60–200 kcal). For experiment 2 the average excess for the 15-h period was 98 kcal (range, 40–160 kcal). We acknowledge that these are only crude estimates inasmuch as indirect calorimetry was not performed continuously throughout the evening and during the night when subjects were sleeping.

It should be noted that when the data from both experiments are combined, the percent elevation above baseline VO2 during the last 6 min of the 2-h recovery was significantly related to the percent elevation in RMR measured the morning after the exercise bout (r = 0.58, P < 0.05). This correlation provides further suggestive evidence that at least some of the RMR elevation was associated with carryover from the elevation of metabolic rate during the measured 2-h recovery period.

Although high-intensity prolonged resistive exercise may result in a significant caloric expenditure beyond the exercise bout itself, this finding has limited application for the general public because participation in such exercise is uncommon. However, these data do have implications for the minority of individuals who perform such activity. These data also suggest the possibility of such acute exercise spuriously elevating the true resting energy expenditure when the latter is being measured the morning after the last exercise bout. The higher RMR values we measured in college wrestlers 12–16 h after strenuous exercise (wrestling practice characterized by intermittent bursts of high-intensity resistive exercise) may have been the result of such residual contamination rather than a training effect (19, 25).

It should be noted that, in experiment 2, the RER values measured the morning after exercise were significantly lower than those measured the morning before exercise. This reflects greater fatty acid oxidation and could be the result of several factors. First, it is possible that the subjects were underfed, reflecting an acute state of negative energy balance that required greater mobilization and oxidation of fatty acids. However, subjects were fed an average of >3,000 kcal on the exercise day, so any energy deficit would appear to be small. It seems possible that the lower RER was the result of changes in macronutrient oxidation after strenuous exercise rather than underfeeding. Studies by Bahr and Sejersted (3) and Bielinski et al. (4) found RER to be depressed for up to 14 h after prolonged steady-state exercise. This represents a shift toward greater fat relative to carbohydrate oxidation during the postexercise period, possibly because relatively more carbohydrate was used for restoration of muscle glycogen stores (16). Strenuous resistive exercise, which primarily utilizes phosphocreatine and carbohydrate for energy substrate (21), may result in substantial fat oxidation during recovery. Flatt (9) suggested that obesity is fundamentally the result of an imbalance in fat oxidation relative to fat intake, with the average long-term respiratory quotient greater than the average food quotient. Strenuous resistive exercise could possibly be beneficial in weight control, not only because of the direct caloric cost of the activity and the residual elevation of postexercise VO2 but also because of greater postexercise fat oxidation. Future research should examine the effect of different modes and intensities of exercise on postexercise nutrient oxidation.

In conclusion, in two separate experiments, a strenuous bout of high-volume resistive exercise produced an elevation of postexercise metabolic rate during a 2-h measured recovery period and a significantly higher RMR when measured ~15 h after the exercise bout. Additionally, in experiment 2, the RER was significantly lower the morning after exercise, reflecting greater fat oxidation. Although the strenuous nature of the exercise may preclude widespread application of these findings to obesity treatment and prevention, such exercise appears to produce a perturbation of resting homeostasis, resulting in a prolonged elevation of metabolic rate.

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